AUTOMATED SKULL 3D GEODISIC AND VOLUMETRIC MEAUSRMENTS FOR CRANIAL MORPHOLOGY TRACKING

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Abstract- **Identification of human remains, including sex estimation and tracking evolutionary changes in the human body, are the focus of many forensic science and anthropological studies. The skull can reveal a great deal about an individual, including information about sex, age, and ancestry, making it an important bone complex for forensic contexts. Most of the skull measurements used in forensic anthropology are external distances and are unable to quantify shape information. In this paper we propose an accurate, automatic 3D geodesic measurement and cranial volumetric measurement that can be used to quantify cranial morphology.**
Keywords - ***Skull*, evolution, morphology, volumetric measurements.**

I. INTRODUCTION AND PREVIOUS WORK

The skull is considered as one of the key skeletal elements in human body due to its anatomical importance and its application in physical anthropology as a way to track changes in cranial size. Cranial size can be used to infer evolutionary adaptations in terms of brain activity levels [1-4].
The skull poses further importance in forensic anthropology, where it is used as a tool to estimate the sex, race and age of unknown skeletal remains [5-7]. The skull is additionally used in facial reconstruction where it can be digitized and "fleshed" by computer reconstruction to give likely facial appearance in life which helps in the identification of missing persons [8-12]. The Procrustes method is typically used to statistically define cranial shape and size as multivariate concepts, which avoids the problems of bias from using simple ratios [13]. However, all of these applications require accurate 3D measurements and detection of some of the main skull landmarks [14]. The main drawback is that most of these measurements are done manually using calipers, which lack accuracy and are extremely subjective to the person performing measurements. All this suggests a need for an automated method for skull landmark detection and automatic measurement. In this paper, we present a method for automatic segmentation, landmarks detection, and 3D and volumetric measurement calculation, in addition we compared our automatic method to manual; measurements and investigated the inter-observability error using digitizer to localize landmarks.

II. MATERIALS AND METHODS

First skull CT data was segmented using Fuzzy C Means (FCM) clustering [16], which is a clustering method that employs fuzzy partitioning where data points can belong to two or more clusters with membership values varying between 0 and 1. FCM is frequently used in pattern recognition [15]. It is an iterative process based on minimization of the objective function in equation 1:

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^{m} \left\| x_i - c_j \right\|^2 \qquad , \quad 1 \le m \le \infty \qquad \textbf{(1)}$$

Four different classes were generated from the FCM. These three classes are, 1) outside the sector, 2) background, 3) skull External bones, 4) skull Internal bones as shown in fig. 1. The resultant segmented contours are then triangulated and 3D surface model was generated from contours as shown in fig. 2.

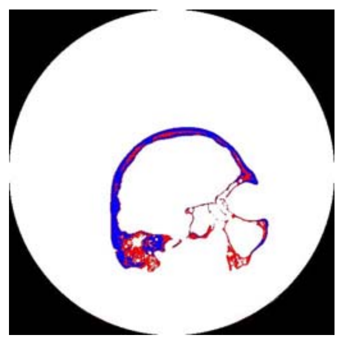

Fig.1. Fuzzy C Mean segmentation

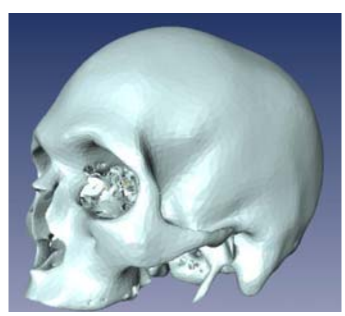

Fig.2. Generated 3D Surface.

First, a reference model was created and aligned using its principle axis. New models are then aligned to the base model using the Iterative Closest Point (ICP) algorithm [17], which is

an iterative alignment algorithm that works by establishing correspondence between pairs of points in the two surfaces then estimating the rigid transformation that best maps the first member of the pair onto the second. Principal curvatures and their directions are then obtained by computing in closed form the eigenvalues and eigenvectors of certain 3x3 symmetric matrices defined by integral formulas, and closely related to the matrix representation of the tensor of curvature [18], where the directional curvature kp function is a quadratic form that satisfies the identity in equation 2.

$$\kappa_p(T) = \begin{pmatrix} t_1 \\ t_2 \end{pmatrix}^t \begin{pmatrix} \kappa_p^{11} & \kappa_p^{12} \\ \kappa_p^{21} & \kappa_p^{22} \end{pmatrix} \begin{pmatrix} t_1 \\ t_2 \end{pmatrix} \qquad \textbf{(2)}$$

The mean curvature H is then calculated by equation 3 where k1 and k2 are the 2 principle curvatures.

$$H = \frac{1}{2}(\kappa_1 + \kappa_2). \qquad \textbf{(3)}$$

Skull mean curvature frontal and cutting views are shown in fig. 3 and 4.

Using curvature data, crest points are calculated [19], the resultant crest lines are then traced using octree as shown in fig. 4.

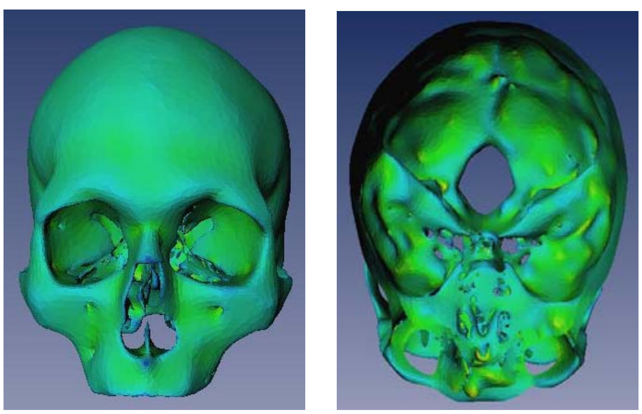

Fig.3. Skull mean curvature mapping

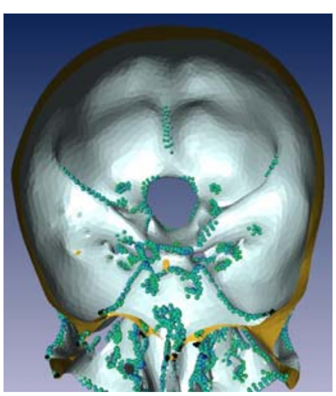

Fig.4. Skull internal crest lines

To get accurate measurements that reflect the real skull dimensions and volume, a set of predefined internal and external anatomical landmarks are automatically detected by utilizing skull geometry, curvature mapping and crest lines. Table 1 shows these landmarks and their extraction description. Using these landmarks, 3D measurements of the internal and external cranial dimensions are calculated. Fig. 5 and 6 show the proposed 3D distances and angles measurements.

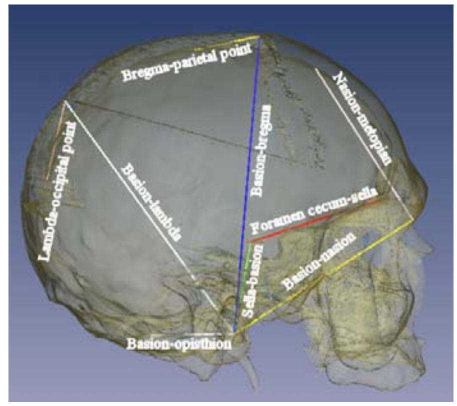

Fig.5. Cranial 3D distance measurements.

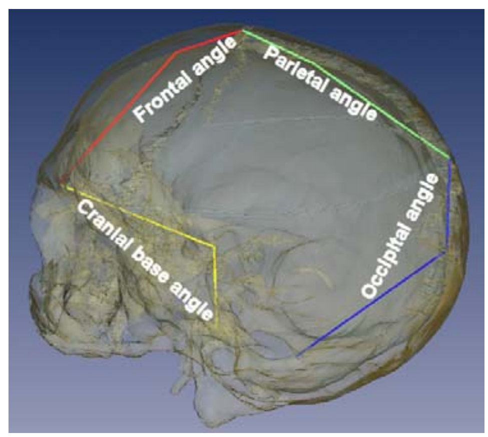

Fig.6. Cranial 3D angle measurements.

In order to get more information about the cranial shape, an estimate of the brain surface is then generated by segmentation of the endocranial surface as shown in fig. 8. The volume and surface area are then calculated for the resulting brain surface. Another measurement that is used as an indication for the development of the brain activity is average cranial vault thickness. We calculated the vault thickness at several locations along the mid-sagittal plane of the skull.

TABLE 1
PROPOSED 3-D MEASURMENTS

Landmark	Extraction Description
Foramen cecum	End point of the frontal crest. midpoint of the anterior margin of the foramen magnum most distance from the bregma
Sella	Superior point on mid sagital plane in dorsum sella
Basion	Point where the anterior margin of the

	foramen magnum is intersected by the mid-sagittal plane
Opisthion	Point at which mid-sagittal plane intersects the posterior margin of the foramen magnum
Bregma	Point where the sagittal and coronal sutures meet
Lambda	Point where the two branches of the lambdoidal sutures meet with sagittal suture
Nasion	Point of intersection of the Naso-Frontal suture and the mid-sagittal plane
Herophili	Intersection of the internal occipital crest with the transverse sulci
Opisthioncranion	Most posteriorly protruding point on the back of the braincase, located in the mid-sagittal plane
Gabella	Most forwardly projecting point in the mid-sagittal plane at the lower margin of the frontal bone
Auriculare	Point on the lateral aspect of the root of the zygomatic process at the deepest incurvature
Foramen ovale	Circular hole that transmits the mandibular nerve
Metopion	Highest projection between nasion and bregma
Parietal point	Highest projection between lambda and bregma
Occipital point	Highest projection between lambda and opisthion

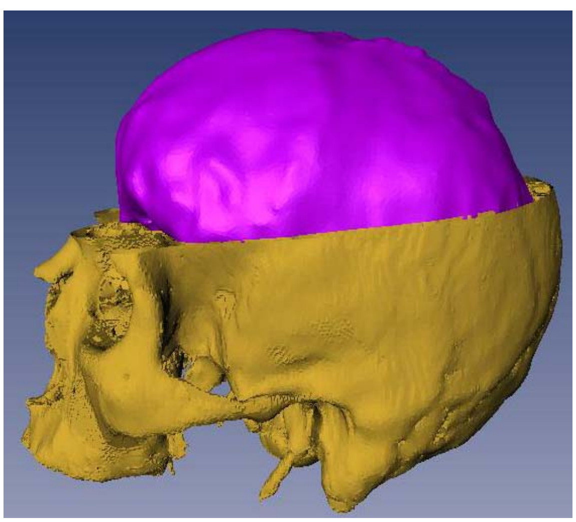

Fig.8. Generated brain surface estimation.

III. RESULTS

Table 2 shows the mean and standard deviation for the 4 manual measurements compared to the automated 3D measurements, and the difference between automatic measurements and mean of the manual measurements, some of the manual measurements were not conducted because it is internal measurements so it is replaced by (N/A) in the table. Fig. 9 shows cranial vault thickness in different locations at the mid-sagittal plane. Our results were found to match the published range values of these parameters [8].

TABLE 2
3-D MEASURMENTS VALUES FOR CASE STUDY

	Manual		Automatic	μ - Automatic
	μ	σ		
F-S	N/A	N/A	6.51	N/A
S-B	N/A	N/A	4.47	N/A
B-B	14.39	0.02	14.34	0.05
B-N	11.01	0.06	10.85	0.16
B-L	12.02	0.04	12.24	0.21
B-O	3.88	0.08	4.02	0.14
N-M	7.22	1.13	7.18	0.03
B-P	6.62	0.10	6.15	0.47
L-O	5.31	0.3	4.99	0.32
N-M-B	94.38	40.96	135.98	41.60
B-P-L	158.47	10.38	147.48	10.98
L-O-O	82.76	9.27	89.00	6.24
B-S-N	N/A	N/A	116.52	116.52
B-W	11.41	0.88	11.93	0.52

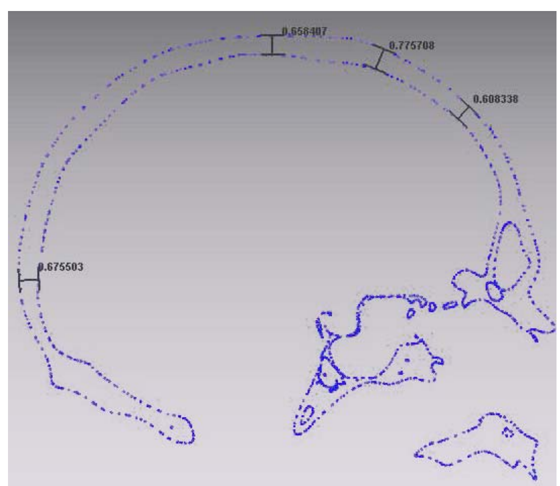

Fig.9. Cranial vault thickness at mid-sagittal plane

V. CONCLUSION

Automated internal and external 3D geodesic and volumetric measurements were calculated that accurately describe the cranial anatomical and morphological shape. Our method overcomes manual techniques of calculating geodesic distances using calipers beside the inter-observability error when using the

digitizers this can be noticed by the high standard deviation for some of the manual measurements in table 2 . It also has the advantage of internal 3D measurements without autopsying the skull. This, in turn, allows accurate study and tracking of the skull. More cases will be investigated in order to verify the output results including a study to develop a model of secular change in the cranial base seen over the past 200-250 years in the American population. Moreover, these measurements will be used as a first step in facial reconstruction and skull identification of sex, age, and race.

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